Source-Related Modeling Issues for the Iron and Steel Industry

AISI Presentation at EPA's 2014 Modeling Workshop

May 20, 2014

Outline of Presentation

Specific source-related modeling issues of concern to the iron and steel sector:

- AERMOD can significantly over-predict for industrial complexes with large (fugitive) heat releases
- We propose a modeling approach for these cases that uses urban dispersion with a large "effective population" and the inclusion of low wind options in AERMOD
- AERMOD also still needs a way to handle buoyant volume and area sources – perhaps using hourly volume source heights?
- There are remaining AERMOD building downwash issues: lack of meandering in light winds and need to account for lift-off effects due to industrial heat releases
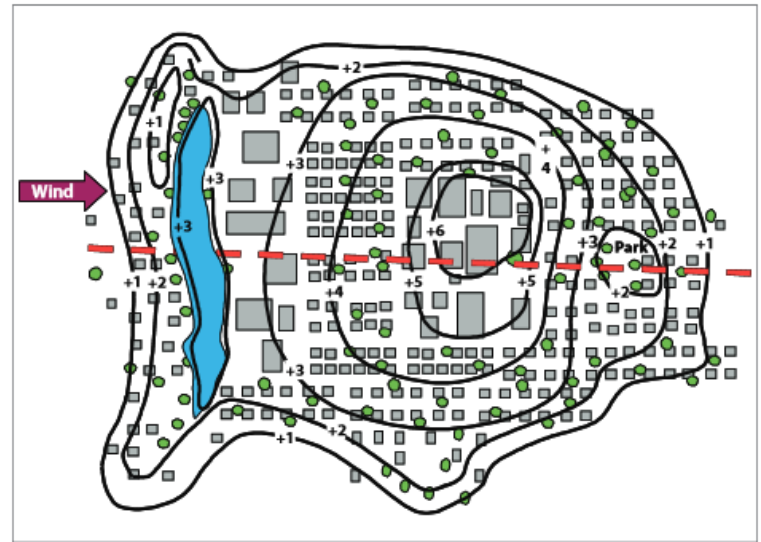
Unique Modeling Aspects of Iron and Steel Industrial Processes: consider urban dispersion

- A major source-related issue is large heat releases in an industrial setting

- Normal assignments of urban vs. rural and population settings result in AERMOD over-prediction

- Industrial processes in geographic areas with large heat releases (i.e., Gary, IN and East Chicago, IN) would be modeled more accurately if considered as urban areas with large "effective populations"

- This would provide an appropriate urbanized treatment of mixing height and temperature lapse rate for dispersion calculations to handle releases within a large heated industrial complex

Current AERMOD Modeling Guidance for Urban Areas

- Implementation guidance allows for urban designation based upon population or land use in a 3-km circle

- Most industrial facilities with large urban-like heat releases do not meet these criteria

- However, AERMOD formulation for urban areas provides for ways to parameterize the "effective urban population" for industrial complexes that act as urban heat islands

Conceptual urban heat island temperature map at night

Determining the "Effective Urban Population"

- The AERMOD urban formulation has a relationship between the urban-rural temperature difference (ΔTu-r) and the effective urban population (P):

    $$\Delta Tu\text{-}r = \Delta Tmax\ [0.1\ \ln(P/Po) + 1.0],$$

    where ΔTmax = 12 deg C and Po = 2,000,000

- The urban-rural temperature difference can be measured for industrial complex areas

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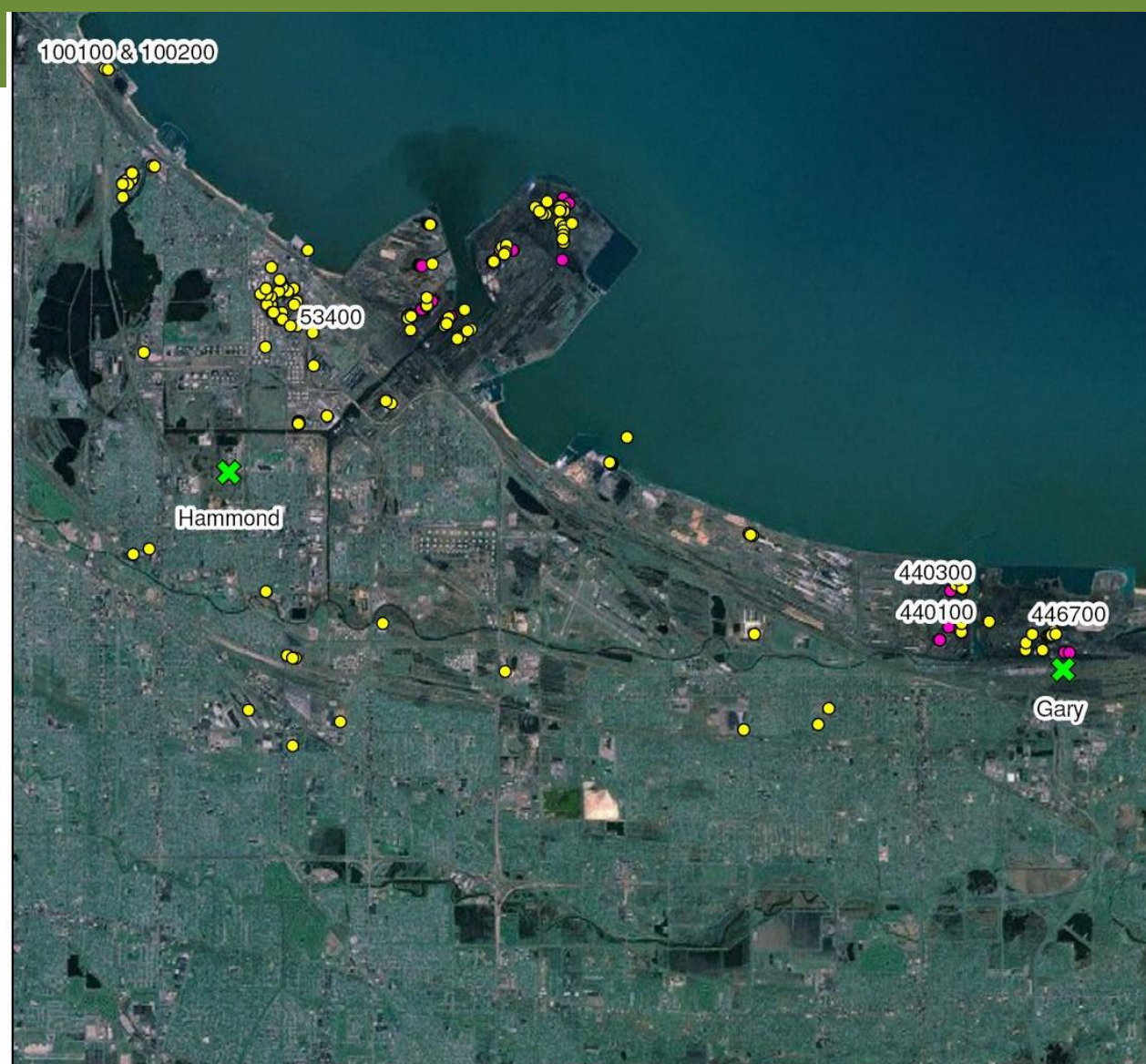
    $$Hu = \alpha\ \rho\ c_p\ \Delta Tu\text{-}r\ u_*,$$

    where α, ρ, c_p, and u_* are known, so $\Delta T_{u\text{-}r} \sim Hu/4$, Hu in w/m^2

Measurements of Urban-Rural Temperature Difference

- The excess temperature in industrial complex areas is now routinely available via satellite databases
- Available satellites are ASTER and LandSat 8
- We have provided EPA with a technical discussion of how to access these databases
- An example of an ASTER satellite temperature map is provided later in this presentation
- Brightness temperature" from satellite can be reviewed for industrial area and compared to urban areas to quantify the "industrial complex heat island" temperature excess

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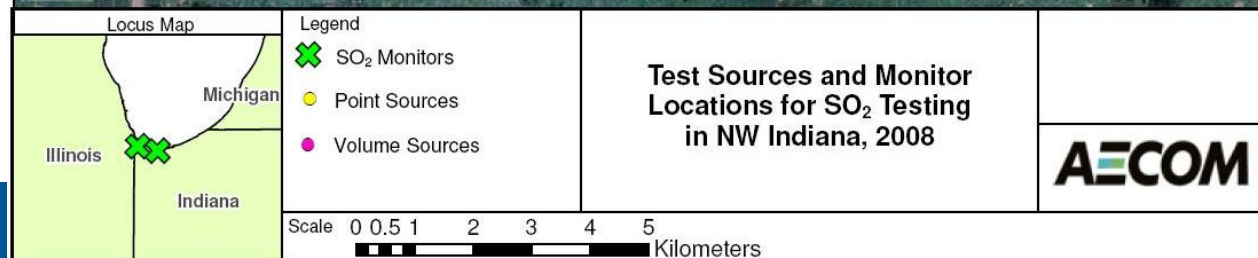
NW Indiana SO_2 evaluation database for AERMOD using actual emissions for 2008
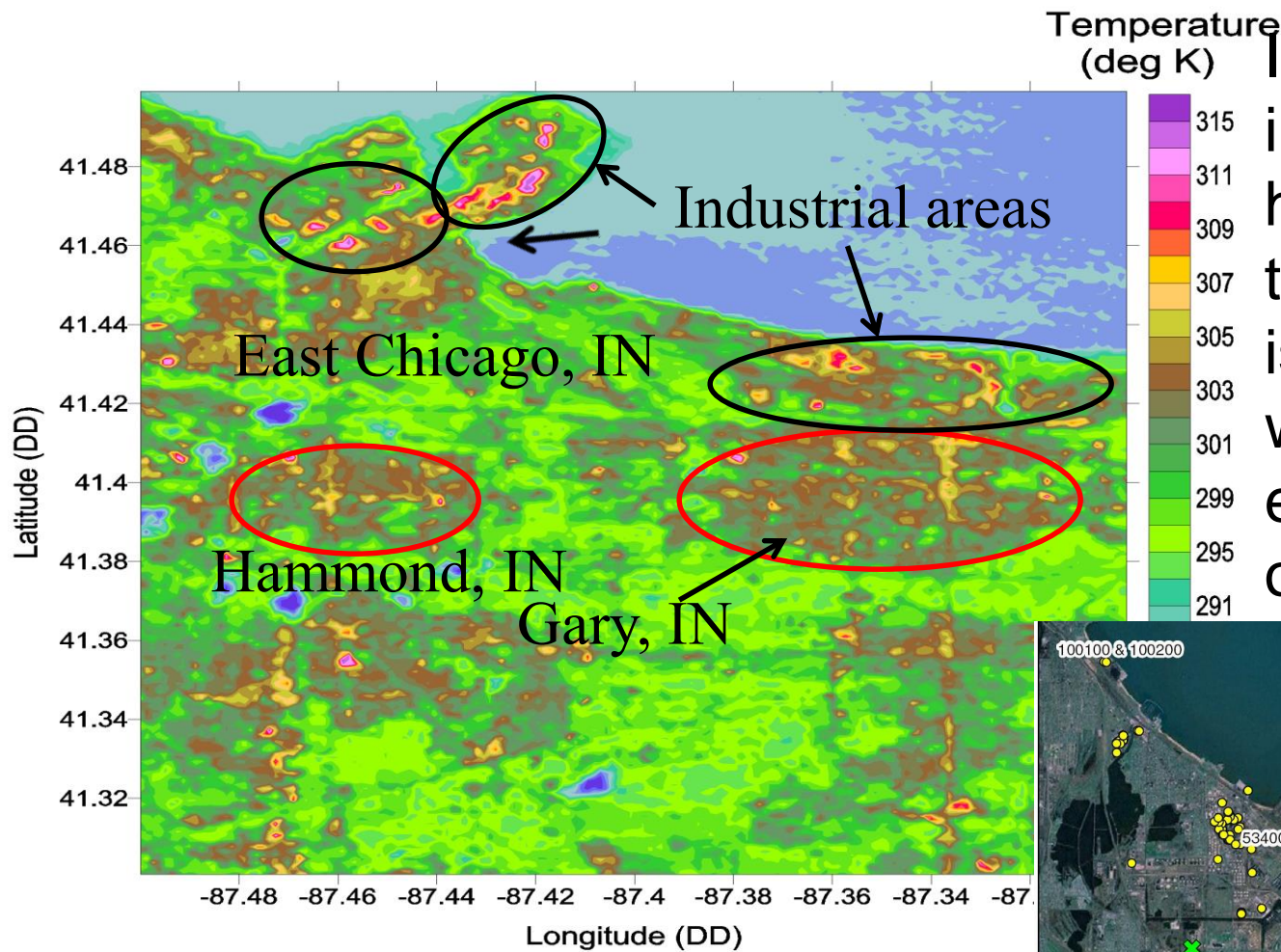
Test Sources and Monitor Locations for SO$_2$ Testing in NW Indiana, 2008

Legend:
- SO$_2$ Monitors
- Point Sources
- Volume Sources

NW Indiana Sources and Two Local SO$_2$ Monitors

Large & complex manufacturing facilities, including steel

Stack (point) and fugitive (volume) SO$_2$ sources

Temperature (deg K)

315
311
309
307
305
303
301
299
295
291

Industrial areas

East Chicago, IN

Hammond, IN

Gary, IN

Brightness temperature from ASTER band June 10, 2008 for 1200 LST

In this case, the industrial complex heat island temperature excess is >= 11-12 deg C, which leads to an effective population of ~1,000,000

Gary Monitor Results for Various AERMOD Runs

| Case | Meteorology | AERMOD options | | | Gary H4H 1-hr. Conc. (μg/m3) |
		Low Wind?	Minimum σ_v & WSPD (m/s)	Urban Sources? (Population)	
1	Default	Default	--	(10k)	1856
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3		LOWWIND1	--	(10k)	1465
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5			0.5	(10k)	LW→ 735
6			--	(1M)	316
7			0.5	(1M)	Large P→ 296
					Monitor H4H: 175 μg/m³

Biggest improvements: AERMET beta u* option (v. 13350), LOWWIND2 with increased minimum wind speed and sigma-v, urban using 1 million population (rather than 10,000)

Summary for NW Indiana Study

- AERMOD (default) run with small urban population over-predicts by about a factor of 10 at two monitors in NW Indiana

- Use of AERMOD beta options for met processing and LOWWIND2 treatment with 0.5 m/s minimum values for wind speed and sigma-v gives factor of 2-3 improvement

- Use of larger effective population with urban treatment provides significant improvement (more than a factor of 2)

- Some over-prediction tendency remains with the best case option, but results are much improved with consideration of urban dispersion with effective urban population and low wind options

Building Downwash Issues: Low Winds and Source-related Lift-off Effects

Building Downwash Complications for Light Winds and Source-Related Effects

- AERMOD *predicted* building downwash effects – sometimes very high concentrations - can occur with nearly calm winds in stable conditions (especially with rural dispersion)

- The peak predictions under these conditions are not expected and have not been adequately evaluated

- These conditions are discussed in Alan Robins chapter on "Flow and dispersion around buildings in light wind conditions" in *Stably Stratified Flows*, edited by Castro and Rockliff, 1994

- Plume lift-off considerations are discussed in "Lift-off of ground-based buoyant plumes" in *Journal of Hazardous Materials*, 1998, by Hanna, Briggs, and Chang

Comments on Light Wind Downwash Issues

- Light winds are associated with extreme stability conditions
- Characteristics of flow and dispersion near buildings in these conditions may be quite unlike those in neutral cases
- Source-related effects become important due to weak ambient turbulence effects in light winds
- In light winds with significant wind meander, building wake effects are <u>very unsteady</u>, but AERMOD does not accommodate this effect in the current formulation
- In fact, AERMOD's meander treatment for low winds only applies to non-downwash dispersion, and was <u>never implemented</u> in the PRIME model implementation within AERMOD

How to Adjust for this Light Wind Effect?

- Suggested approach would be to reduce downwash impact for very low winds due to wind direction unsteadiness / meander
- The Danish OML model accounts for the intermittent nature of the downwash (see Genikhovich-Snyder approach in http://www2.dmu.dk/1_viden/2_Publikationer/3_arbrapporter/rapporter/AR123.pdf, Section 5.2)
- Basically, the downwash vs. non-downwash treatment is treated with a weighting factor that depends upon the wind intermittency
- An AERMOD workgroup should take this on as a key issue to be resolved

Downwash for Sources with Excess Heat Releases

- In cases with significant heat releases, plumes will resist downwash effects, especially in light wind cases, and lift off from the building – PRIME does not consider this effect

- Heat can be estimated with a buoyancy flux term, Fb

- Hanna, Briggs, and Chang suggest a combined dimensionless buoyancy flux, $F^{**} = Fb/(Ueff^3W)$, where Fb is the buoyancy flux, Ueff is the effective wind speed and W is the initial plume width

- Possible approach similar to low wind intermittency: Use a weighting factor between lift-off conditions (no downwash) and non-lift-off conditions (normal downwash) ranging from 0 to 1 from Hanna, Briggs, Chang paper:

    exp (-6F**^0.4)

Next Steps: Enhancements to AERMOD for Next Appendix W Update

- Add consideration of urban dispersion option for industrial complex heat islands
- Characterize large effective population as appropriate
- Adopt low wind speed improvements as default options
- Provide a way to handle buoyant volume and area sources
- Solve issue with intermittent building downwash for nearly calm winds using weighting factor
- Use a weighting factor approach to account for limited or no downwash for sources in heated environments

- In the meantime, allow case-by-case applications of these improvements

For Additional Information…

See the AISI link for related documents at

http://ow.ly/wTwKz

Appendix: Full Set of Presentation Slides

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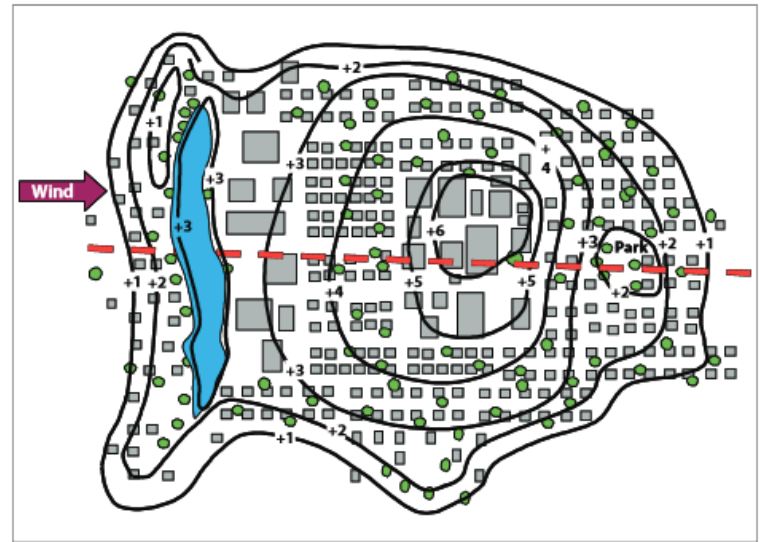
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- Alternatively, if the excess heat release (flux, Hu) is known, then this can be related to the urban-rural temperature difference, as noted in the AERMOD formulation:

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    where α, ρ, c_p, and u_* are known, so $\Delta T_{u\text{-}r} \sim Hu/4$, Hu in w/m^2

Examples of Effective Population Calculation (P)

Case 1: urban-rural temperature difference is provided:
ΔT_{u-r} = 10 deg C

P = Po exp $[10(\Delta T_{u-r} /\Delta T_{max}-1.0)]$, where ΔT_{max} = 12 deg C, and Po = 2,000,000

P ~ 400,000

Case 2: anthropogenic heat flux, Hu, is estimated for the entire source and divided by the source area to provide average heat flux in watts/m^2 for the industrial area: suppose Hu = 40 watts/m^2

ΔT_{u-r} ~ Hu/4 = 10 deg C

Then, from the example above, P ~ 400,000

# Measurements of Urban-Rural Temperature Difference

- The excess temperature in industrial complex areas is now routinely available via satellite databases
- Available satellites are ASTER and LandSat 8
- We have provided EPA with a technical discussion of how to access these databases
- An example of an ASTER satellite temperature map is provided later in this presentation
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AISI field database tested to illustrate how urban dispersion with large effective population improves AERMOD performance:

NW Indiana SO_2 evaluation database for AERMOD using actual emissions

Northwest Indiana SO_2 Evaluation for AERMOD Using Actual Emissions for 2008
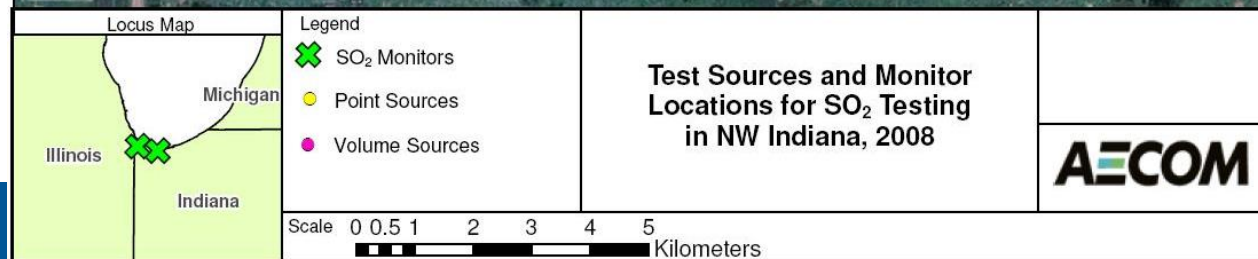
- Indiana Department of Environmental Management (IDEM) provided an inventory of annual average SO_2 emissions for 2008
- AERMOD predicted results using annual average emission rates were compared to measurements at two local SO_2 monitors
- AERMOD evaluation study was submitted to EPA in June 2012, but was later updated with AERMOD version 12345
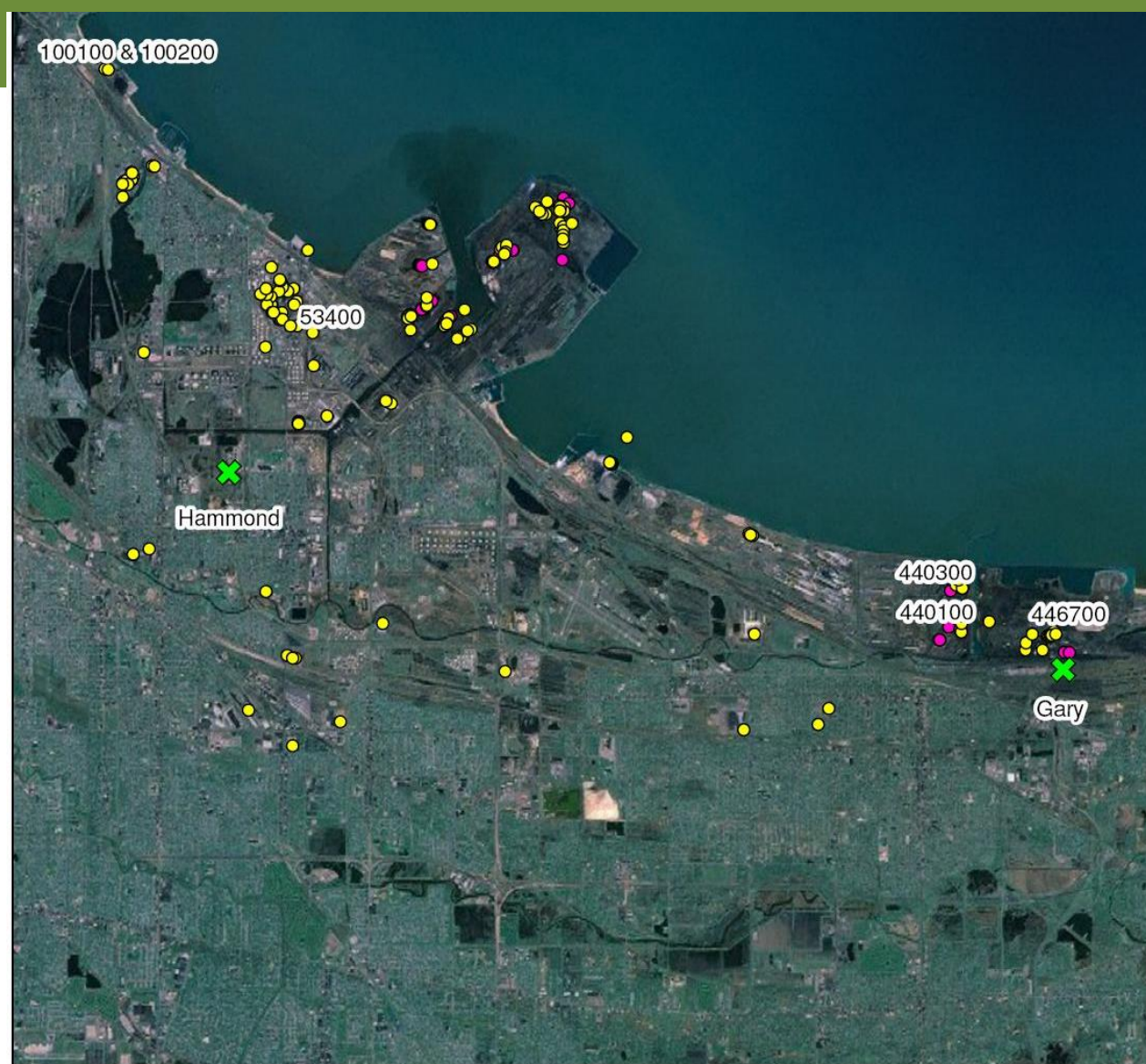
NW Indiana Sources and Two Local SO$_2$ Monitors

Large & complex manufacturing facilities, including steel
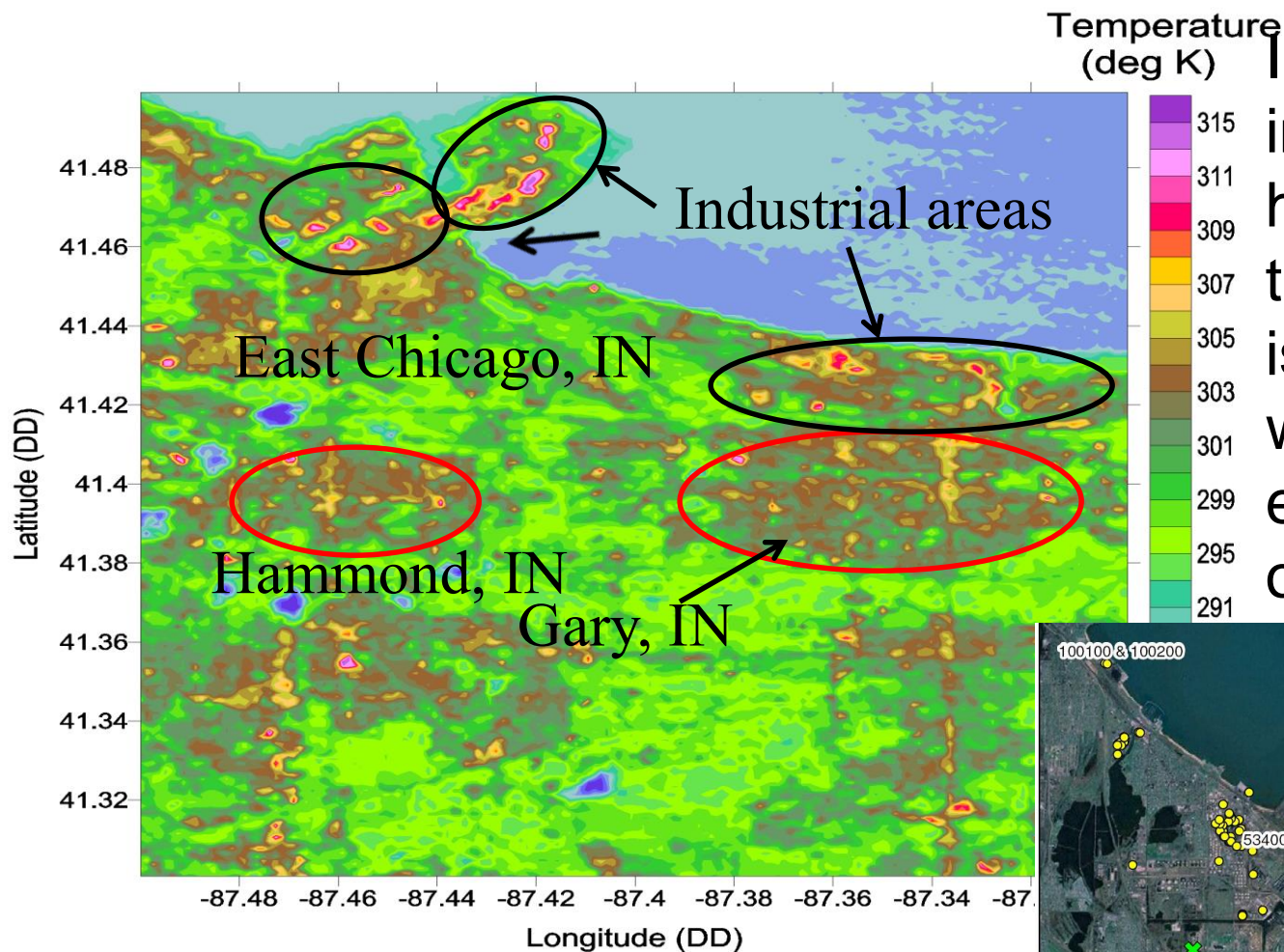
Stack (point) and fugitive (volume) SO$_2$ sources

Legend
- ✖ SO$_2$ Monitors
- ● Point Sources
- ● Volume Sources

Test Sources and Monitor Locations for SO$_2$ Testing in NW Indiana, 2008

AECOM

Scale 0 0.5 1 2 3 4 5 Kilometers

Source – Receptor Relationships for This Database

- Area is generally flat
- There are numerous SO_2 sources, ranging from tall point sources to relatively low volume sources
- Sources are in environments with large excess heat releases
- Peak impacts appear to be due to many different causes, many associated with low wind speeds:
  - For rural dispersion, low nocturnal mixing heights and building downwash in low winds with limited dilution lead to high predictions
  - For urban dispersion, the limited mixing leads to high predictions in low winds with limited dilution if low population value is input
- Discussion that follows focuses upon use of urban dispersion, but with small vs. larger effective population
- We also tested new AERMOD low wind options

In this case, the industrial complex heat island temperature excess is >= 11-12 deg C, which leads to an effective population of ~1,000,000

Brightness temperature from ASTER band June 10, 2008 for 1200 LST
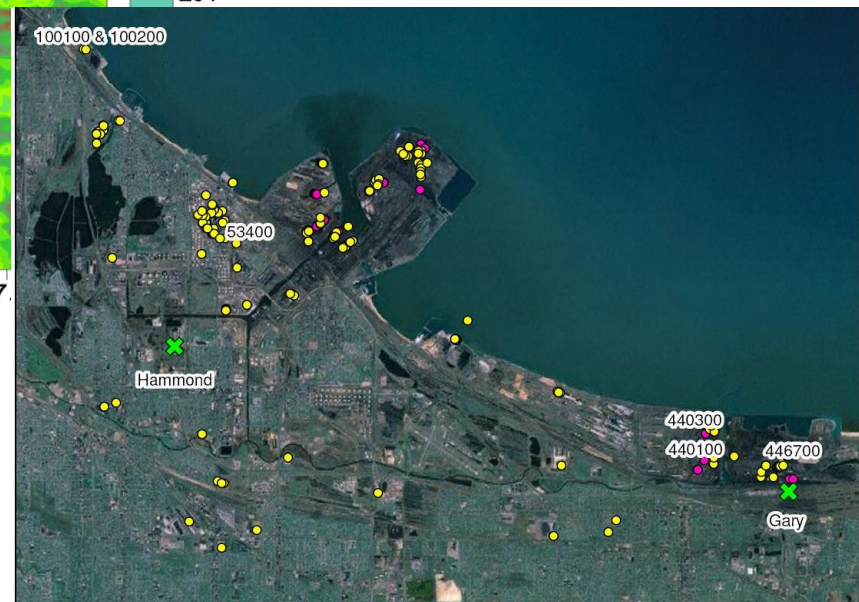
AERMOD Version 12345* Model Tests Conducted for NW Indiana for Modeled Year 2008

Case	Meteorology	AERMOD options		
		Low Wind?	Minimum σ_v & WSPD (m/s)	Urban Sources? (Population)
1	Default	Default	--	(10k)
2	Adjusted u*	Default	--	(10k)
3		LOWWIND1	--	(10k)
4	Adjusted u*	LOWWIND2	--	(10k)
5			0.5	(10k)
6			--	(1M)
7			0.5	(1M)

*with Theta-star fix as installed in AERMET 13350

Gary Monitor: Case 1 Daily Maxes

AERMOD urban with very small population over-predicts by more than a factor of 10 (urban boundary layer only ~100 m); limited boundary layer height is a primary cause

Case 1 H4H: 1856 µg/m³
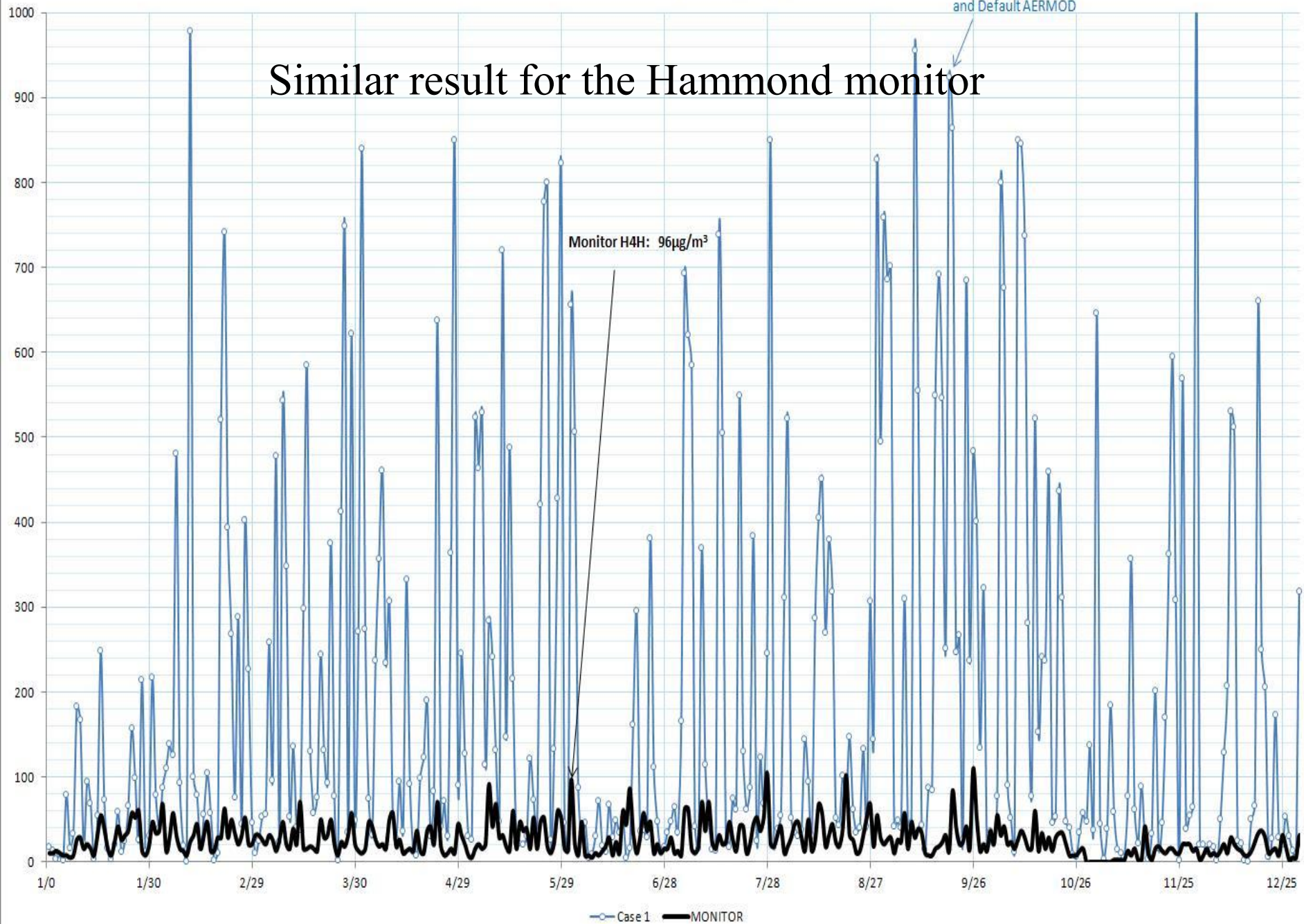Default AERMET
and Default AERMOD

AERMOD

Monitor H4H: 175µg/m³
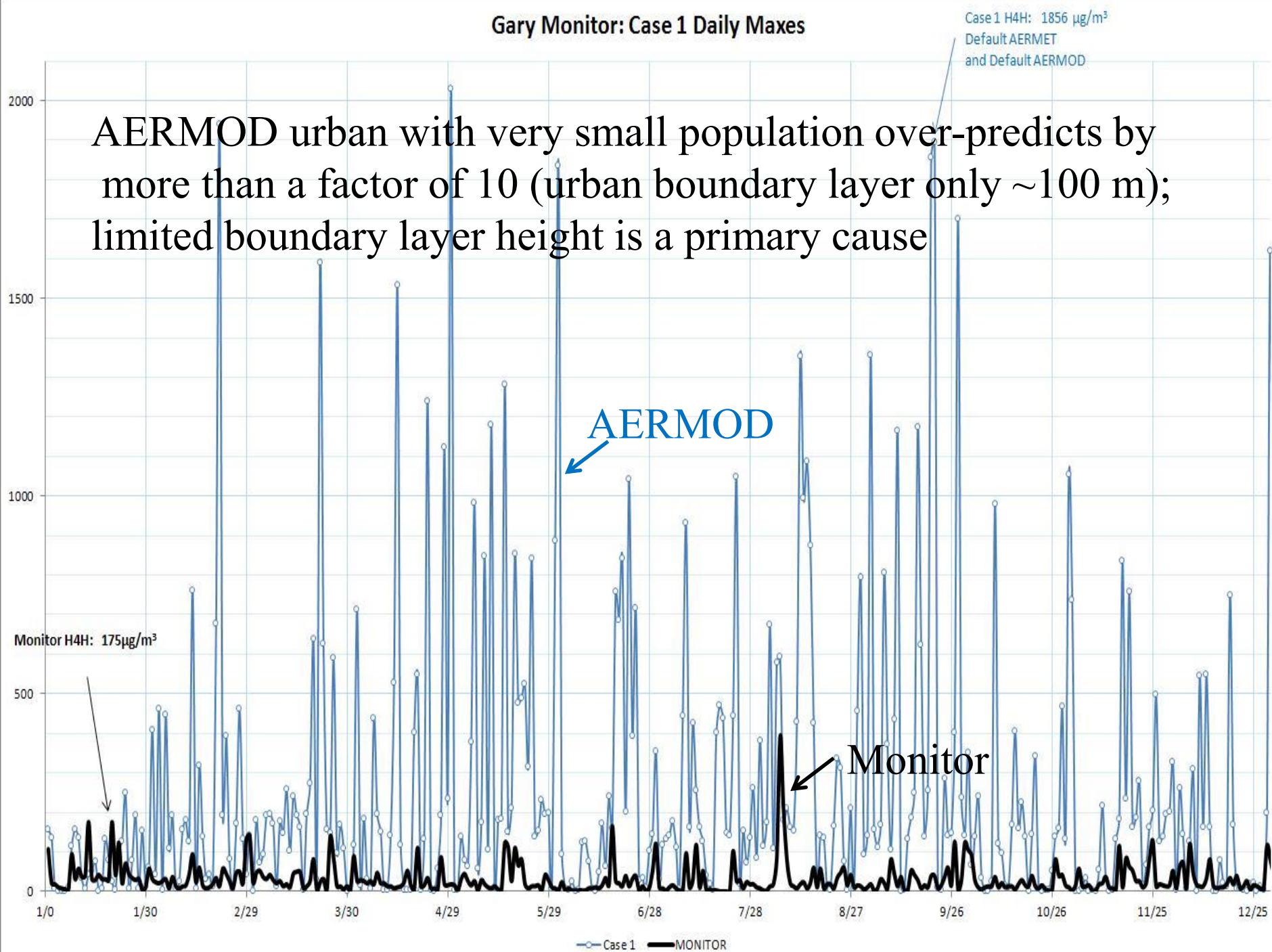
Monitor

Hammond Monitor: Case 1 Daily Maxes

Case 1 H4H: 925 μg/m³
Default AERMET
and Default AERMOD

Similar result for the Hammond monitor

Monitor H4H: 96μg/m³

Case 1 ○ MONITOR

Gary Monitor Results for Various AERMOD Runs

| Case | Meteorology | AERMOD options | | | Gary H4H 1-hr. Conc. (μg/m3) |
		Low Wind?	Minimum σ_v & WSPD (m/s)	Urban Sources? (Population)	
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4	Adjusted u*	LOWWIND2	--	(10k)	1190
5			0.5	(10k)	LW→ 735
6			--	(1M)	316
7			0.5	(1M)	Large P→ 296
					Monitor H4H: 175 μg/m^3

Biggest improvements: AERMET beta u* option as fixed, LOWWIND2 with increased minimum wind speed and sigma-v, urban using 1 million population (rather than 10,000)

Gary Monitor: Case 7 (Modified AERMET) Daily Maxes

Best case AERMOD much better,
still over-predicts by a factor of 1.7

Case 7 H4H: 297μg/m³
AERMET with u*
and LOWWIND2 AERMOD
and Urban Pop.:1 million
and Minimum sigma-v & WSPD

Monitor H4H: 175μg/m³

Case 7   MONITOR
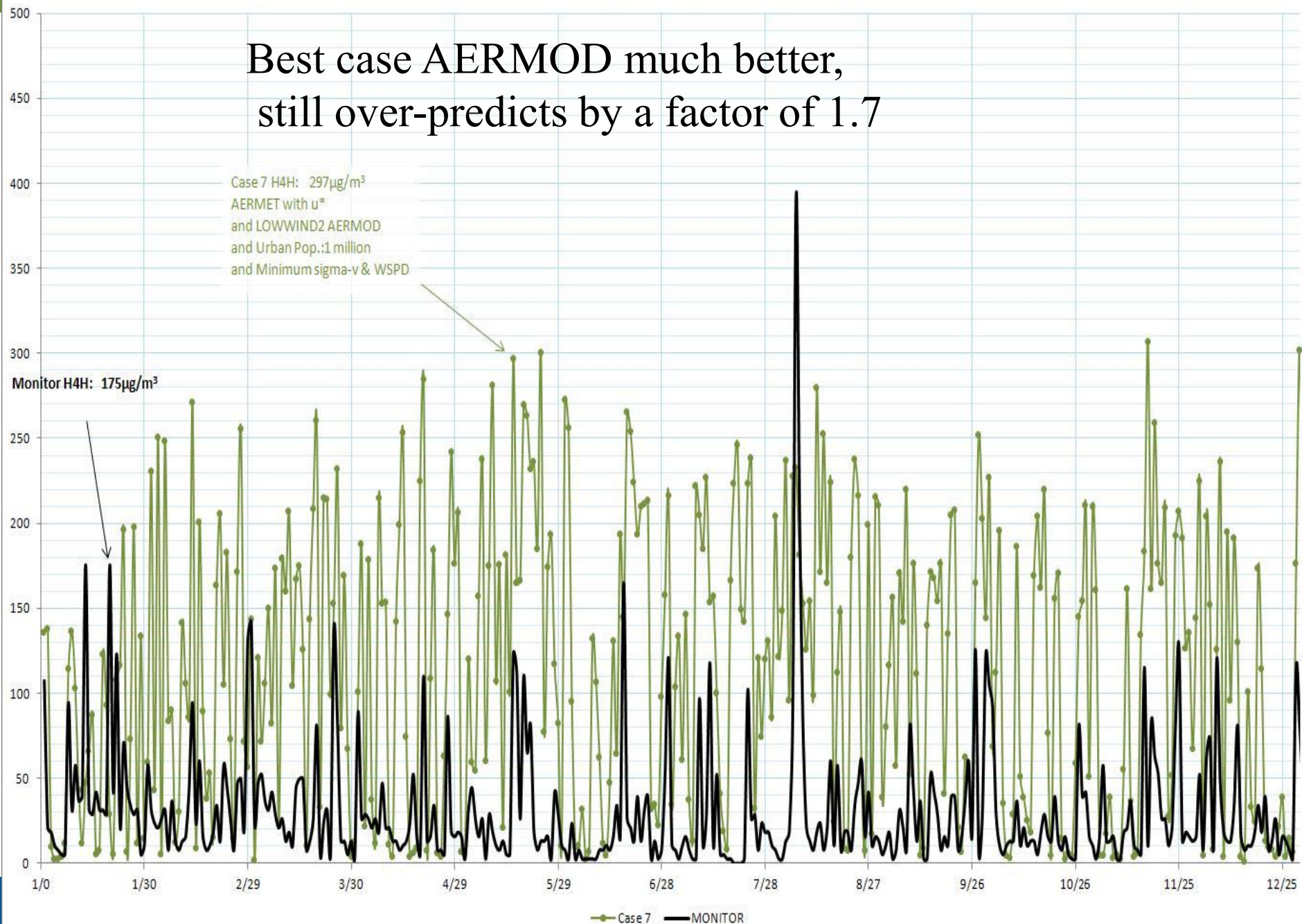
Hammond Monitor Results from AERMOD Runs

| Case | Meteorology | AERMOD options | | | Hammond H4H 1-hr. Conc. (μg/m3) |
		Low Wind?	Minimum σ_v & WSPD (m/s)	Urban Sources? (Population)	
1	Default	Default	--	(10k)	925
2	Adjusted u*	Default	--	(10k)	706
3		LOWWIND1	--	(10k)	567
4	Adjusted u*	LOWWIND2	--	(10k)	565
5			0.5	(10k)	LW→ 378
6			--	(1M)	165
7			0.5	(1M)	Large P→153
					Monitor H4H: 96 μg/m³

Biggest improvements: AERMET beta u* option as fixed, LOWWIND2 with increased minimum wind speed and sigma-v, urban using 1 million population rather than 10,000

Hammond Monitor: Case 7 (Modified AERMET) Daily Maxes

Case 7 H4H: 152 µg/m³
AERMET with u*
and LOWWIND2 AERMOD
and Urban Pop.::1 million
and Minimum Sigma-v & WSPD

Monitor H4H: 96µg/m³

Best case AERMOD again much better, over-predicts by a factor of 1.6
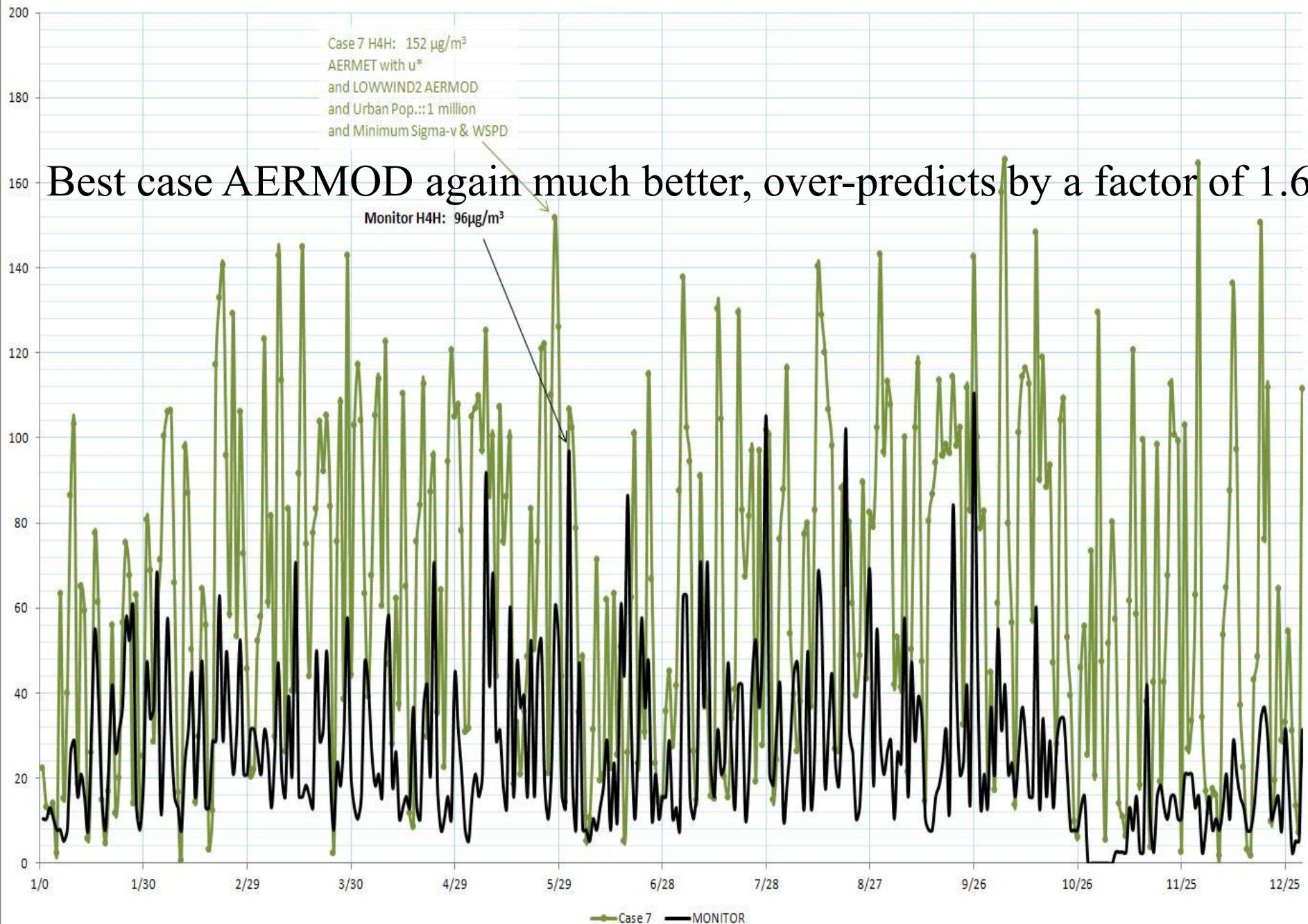
Case 7   MONITOR

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- AERMOD *predicted* building downwash effects – sometimes very high concentrations - can occur with nearly calm winds in stable conditions (especially with rural dispersion)

- The peak predictions under these conditions are not expected and have not been adequately evaluated

- These conditions are discussed in Alan Robins chapter on "Flow and dispersion around buildings in light wind conditions" in *Stably Stratified Flows*, edited by Castro and Rockliff, 1994

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- Possible approach similar to low wind intermittency: Use a weighting factor between lift-off conditions (no downwash) and non-lift-off conditions (normal downwash) ranging from 0 to 1 from Hanna, Briggs, Chang paper:

    exp (-6F**^0.4)

Next Steps: Longer-Term vs. Short-Term Modeling Approaches for Iron and Steel Emission Sources

- Longer term (promulgation of Appendix W update – 2016?):

- Add consideration of urban dispersion option for industrial complex heat islands
- Characterize large effective population as appropriate
- Adopt low wind speed improvements as default options
- Provide a way to handle buoyant volume and area sources
- Solve issue with building downwash for nearly calm winds using intermittency approach for weighted average
- Use a weighted average approach to account for limited or no downwash for sources in heated environments

Next Steps: Longer-Term vs. Short-Term for Iron and Steel Emission Sources

- Shorter term (until Appendix W update):

- Status quo modeling approaches do not result in credible AERMOD results – there are substantial over-predictions

- Without recommended changes, modeling cannot be used to conclude that there are NAAQS violations in the vicinity of iron and steel industry sources with significant excess heat releases

- In the interim, allow on a case-by-case basis (without impossible hurdles) the use of urban dispersion with large effective population, low wind speed options, and downwash adjustments for low winds and/or heated buildings